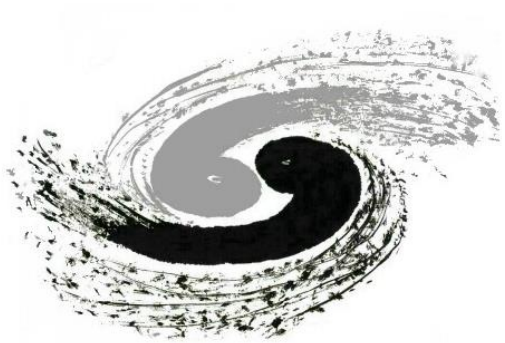
Search for charmonium-like states decay into light hadrons at BESIII



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on behalf of BESIII collaboration

Outline

- Introduction
- $e^+e^- \to p\bar{p}\pi^0$
- $e^+e^- \to \phi\phi\phi(\omega)$
- $e^+e^- \to \eta Y(2175)$
- Summary

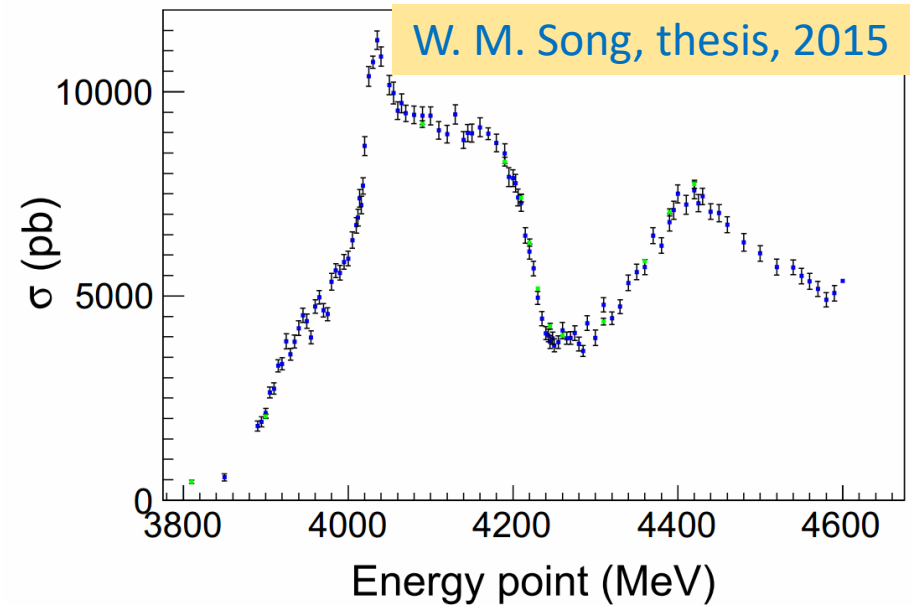
Introduction

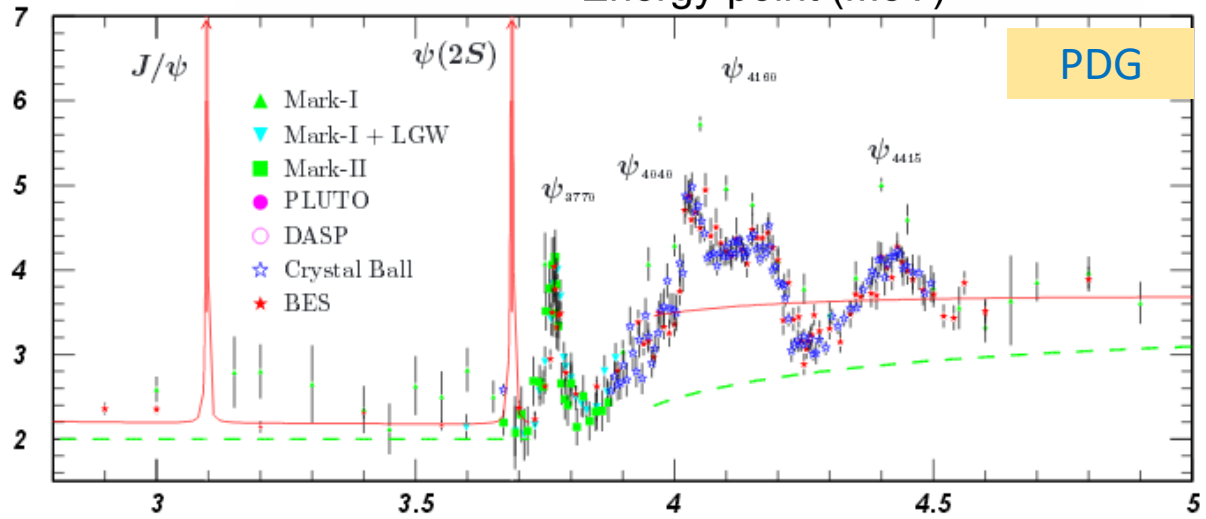
A series vector charmonium-like states, $e.g.$ $Y(4260)$ only observed in charmonium transitions, not hadronic decays.

R- value is around 4 at $\sqrt{s} = 4 - 4.6$ GeV, so total cross section is ~16 nb, 10 nb for open-charm, what about other 6 nb? only charmonium transition?

$Y(4260)$ could have sizeable charmless decay fraction in some theoretical models

PLB628,215, CPC39,063102

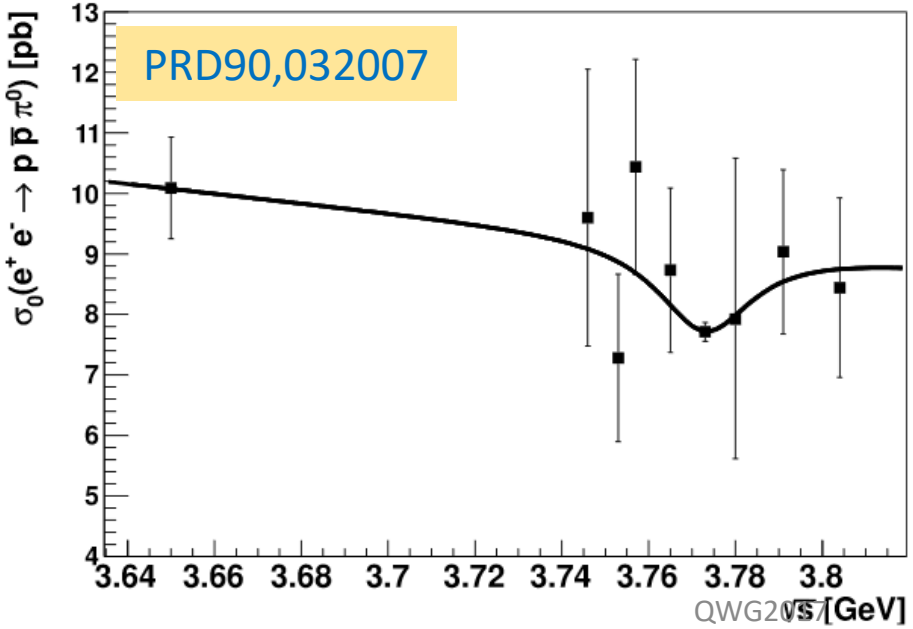




Cross section of $e^+e^- \to p\bar{p}\pi^0$

PLB771,45(2017)

- Cross sections around 3.77 GeV were measured, two solutions with interference, one has $\sigma(\psi(3770) \to p\bar{p}\pi^0) = 33.8 \pm 1.8 \pm 2.1$ pb, one has upper limit 0.22 pb at 90% C.L.
- Search for vector charmonium decaying to $p\bar{p}\pi^0$
- Can be used to estimate the cross section of $p\bar{p} \to X\pi^0$ at PANDA



Event selections

- Two charged tracks with opposite charge.
- Combine time of flight and dE/dx to calculate the confidence level for π, K and p hypothesis. $\mathrm{Prob_p} > Prob_\pi, Prob_p > Prob_K$
- One proton, one anti-proton.
- At least two EMC showers, $E_{EMC} > 25$ MeV in barrel, $E_{EMC} > 50$ MeV in endcap.
- Angle between photon and anti-proton larger than 30 degree.
- 4 constraints kinematic fit. Use the one combination with least χ^2_{4C}
- $|M(\gamma\gamma) - M_{\pi^0}| < 15$ MeV
- Background come from $\gamma p\bar{p}, \gamma\gamma p\bar{p}, \gamma\gamma\gamma p\bar{p}$, estimated using π^0 sideband.

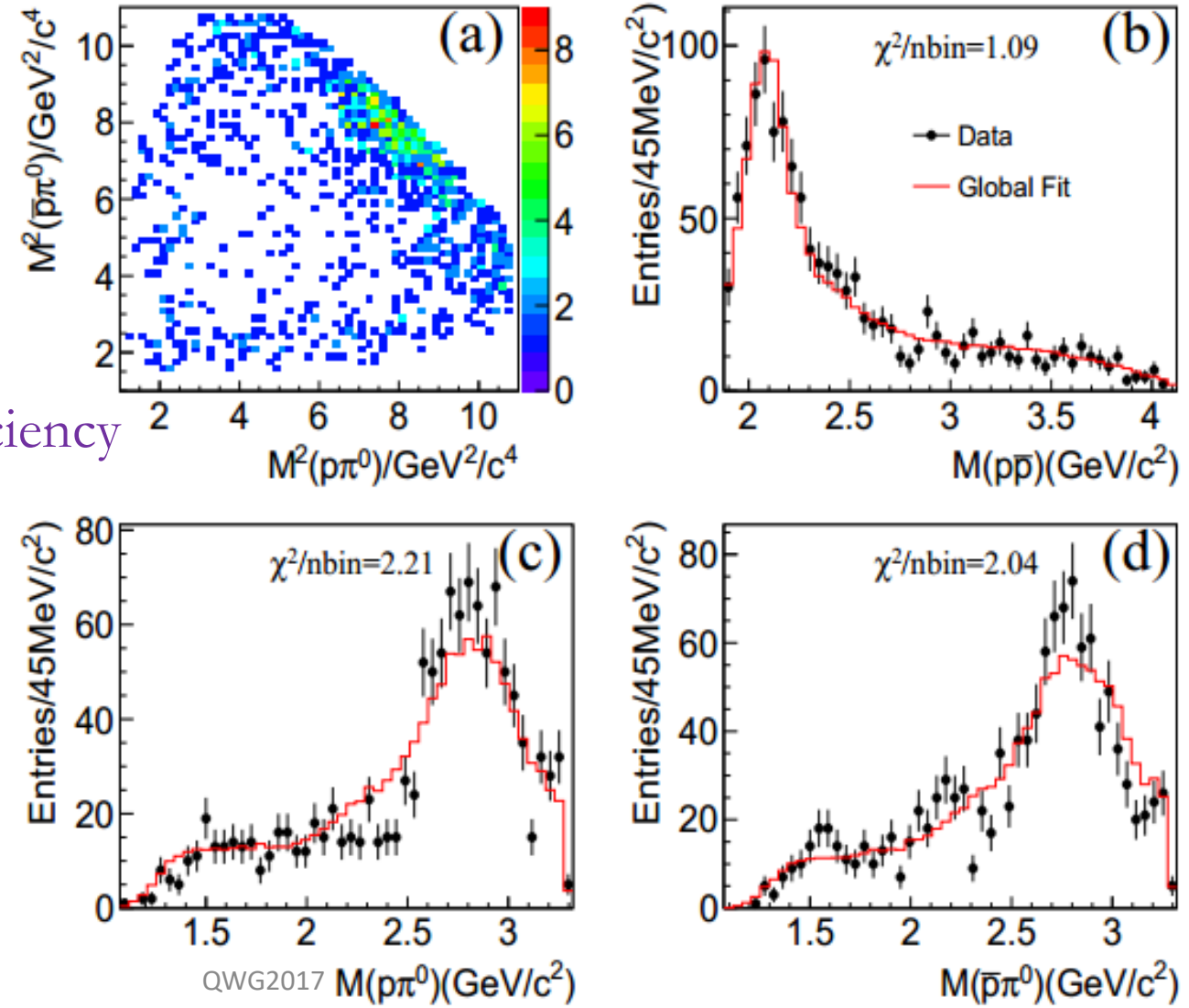
Dalitz plot at 4.258 GeV

Multi intermediate baryons

$$N^*, \Delta^* \to p\pi^0$$

And $\rho^*/\omega^* \to p\bar{p}$

To determine the detection efficiency correctly, we perform partial wave analysis (PWA).



Partial wave analysis

- Covariant tensor formalism (J. Phys. G28,233)
- Parameterization of $\rho^*/N^*/\Delta^*$: Breit-Wigner (RPD80,052004)
- Direct process of $e^+e^- \to p\bar{p}\pi^0$: 1^{--} or 3^{--} $p\bar{p}$ system
- Resonance with significance larger than 5σ are retained

Result:

Data at $\sqrt{s} = 4.189 - 4.600$ GeV,

Described by $N(1440), \rho(2150), \rho_3(1990)$ and 1^{--} phase space.

Data at $\sqrt{s} = 4.008 - 4.085$ GeV:

Described by $N(1520), N(2570), \rho(2150), \rho_3(1990)$ and 1^{--} phase space

Born cross section

$$\sigma^B = \frac{N^{\rm obs}}{\mathcal{L}\cdot(1+\delta^r)\cdot(1+\delta^v)\cdot\epsilon\cdot\mathcal{B}_{\pi^0}},$$

$(1+\delta^r)$:
radiative correction
$(1+\delta^v)$:
vacuum polarization corrections,

Efficiency comes from PWA

$\sqrt{s}$ (GeV)	$\mathcal{L}$ [pb^{-1}]	$(1+\delta^r)$	$(1+\delta^v)$	$N^{\rm obs}$	ϵ[%]	σ^B[pb]
4.008	482.0	0.967	1.044	1074 ± 33	43.9 ± 0.9	$5.09 \pm 0.18^{+0.26}_{-0.24}$
4.085	52.6	0.992	1.052	106 ± 11	43.7 ± 1.4	$4.47 \pm 0.46^{+0.27}_{-0.21}$
4.189	43.1	1.025	1.056	75 ± 9	44.7 ± 1.0	$3.64 \pm 0.43^{+0.18}_{-0.19}$
4.208	54.6	1.031	1.057	93 ± 10	44.9 ± 1.6	$3.52 \pm 0.39^{+0.17}_{-0.22}$
4.217	54.1	1.034	1.057	82 ± 10	43.4 ± 1.3	$3.24 \pm 0.37 \pm 0.18$
4.226	1047.3	1.037	1.056	1611 ± 41	45.2 ± 0.5	$3.15 \pm 0.08 \pm 0.14$
4.242	55.6	1.042	1.056	89 ± 9	44.6 ± 1.1	$3.30 \pm 0.36^{+0.19}_{-0.15}$
4.258	825.6	1.048	1.054	1203 ± 35	43.4 ± 0.5	$3.08 \pm 0.10^{+0.14}_{-0.15}$
4.308	44.9	1.063	1.053	53 ± 8	46.0 ± 1.4	$2.32 \pm 0.33^{+0.15}_{-0.10}$
4.358	539.8	1.081	1.051	668 ± 26	44.7 ± 1.1	$2.48 \pm 0.11^{+0.13}_{-0.12}$
4.387	55.2	1.087	1.051	57 ± 8	47.5 ± 1.8	$1.92 \pm 0.26 \pm 0.10$
4.416	1028.9	1.098	1.053	1133 ± 34	44.6 ± 0.6	$2.16 \pm 0.10^{+0.10}_{-0.11}$
4.600	566.9	1.124	1.055	474 ± 22	43.8 ± 0.8	$1.63 \pm 0.08 \pm 0.08$

Born cross sections

No significant signal of any vector charmonium

$$\sigma(s) = \left|\sqrt{\sigma_{\rm con}} + \sqrt{\sigma_Y}\frac{m\Gamma}{s - m^2 + im\Gamma}\exp(i\phi)\right|^2$$

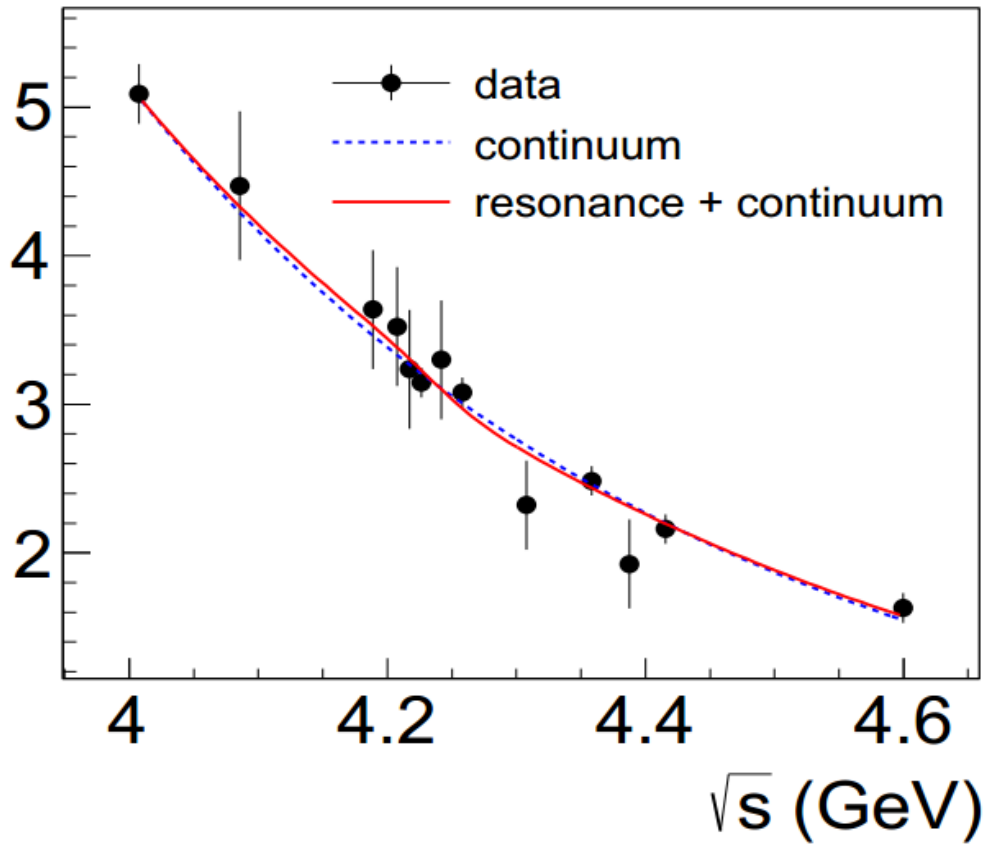
cross section of continuum process

$\sqrt{\sigma_{con}} \propto \frac{1}{s^n}$

Second item represents the vector charmonium ($Y(4260)$), mass (m) and width Γ are fixed to PDG .

Upper limit of $\boldsymbol{\sigma(e^+e^- \to Y(4260) \to p\bar{p}\pi^0)}$ is 0.01 pb at 90\% C.L.

$\boldsymbol{n = 4.2 \pm 0.4}$

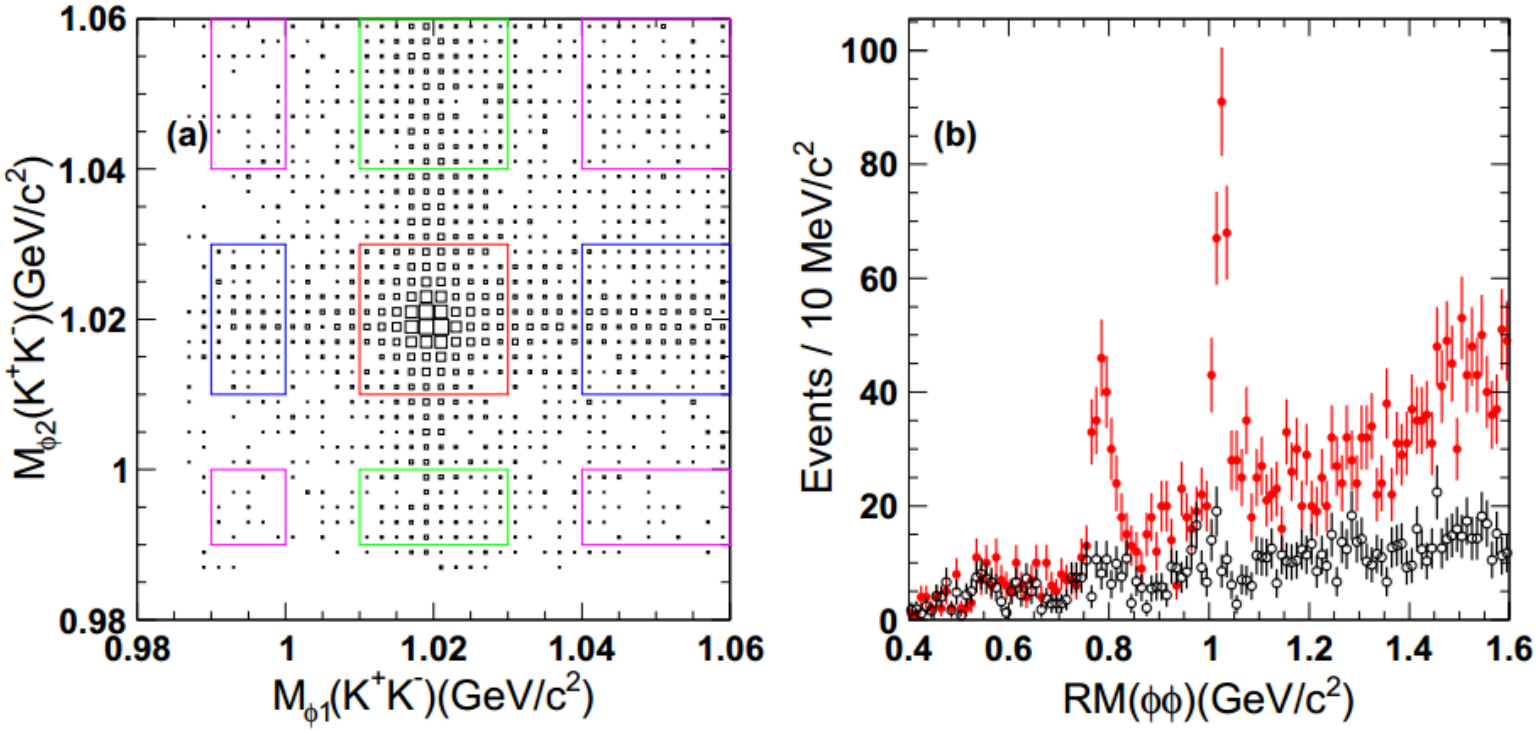


Cross sections of $e^+e^- \to \phi\phi\phi(\omega)$

PLB774,78(2017)

- Large ratio $\sigma(e^+e^- \to J/\psi c\bar{c})/\sigma(e^+e^- \to J/\psi X)$~0.6 from BaBar and Belle.
- Surprisingly large fraction of $\sigma(e^+e^- \to J/\psi X)$
- Validate theoretical investigations with double/triple quarkonia
- Study multi stangeonia at BESIII
- Search for the vector charmonium-like states
- Ratio $\frac{\sigma(e^+e^- \to \phi\phi\omega)}{\sigma(e^+e^- \to \phi\phi\phi)} \approx \frac{\sigma(e^+e^- \to \gamma^* gg \to 2(s\bar{s}) + (u\bar{u}+d\bar{d})/\sqrt{s})}{\sigma(e^+e^- \to \gamma^* gg \to 3(s\bar{s}))}$ range from 1 to 2.5
- Helpful to understand the production mechanism of e^+e^- to multi quarkonia

- Reconstruct two ϕ (K^+K^-) and investigate the recoil system
- Recoil mass $RM(\phi\phi) = \sqrt{\left(E_{cms} - E_{\phi\phi}\right)^2 - p_{\phi\phi}^2}$



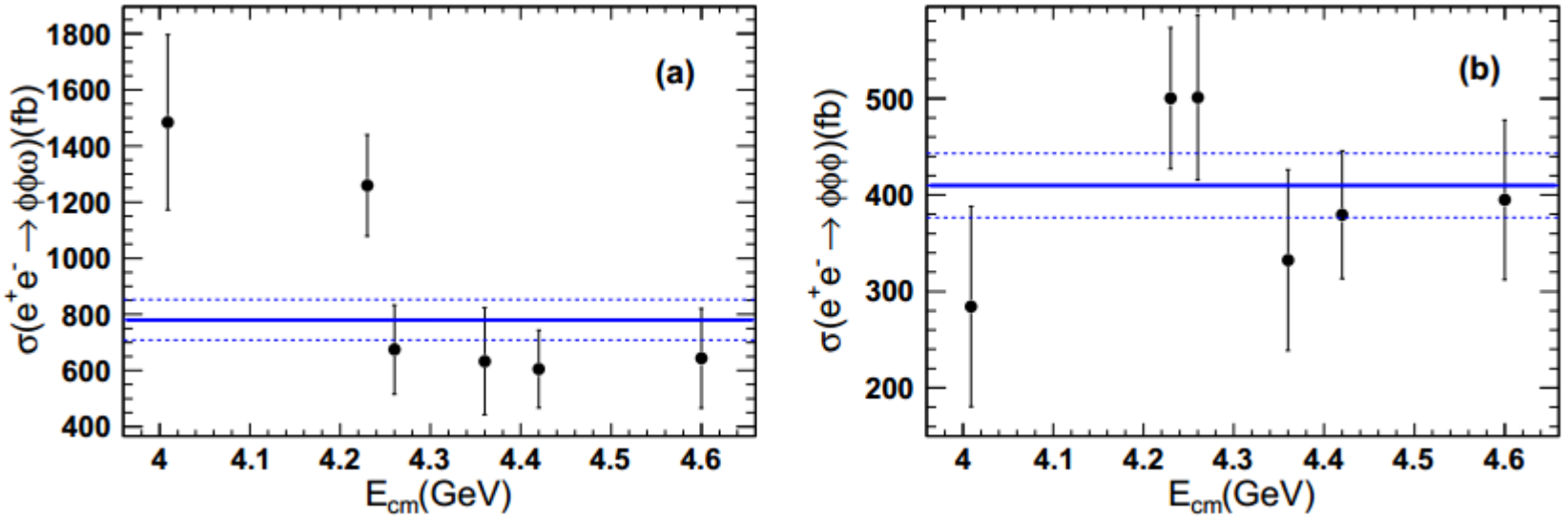
2D sidebands to estimate backgrounds.
Determine the normalized factor with 2D fit.

Clear ω and ϕ signal.
Black circles are background from 2D sidebands

Born cross sections

$$\sigma^{\mathrm{B}} = \frac{N^{\mathrm{obs}}}{\mathcal{L}_{\mathrm{int}} \cdot (1+\delta^{r}) \cdot (1+\delta^{v}) \cdot \epsilon \cdot \mathcal{B}^{2}}$$

Efficiency of the reconstructed two ϕ depends on their angle θ,
Weight the phase space MC on $\cos\theta$

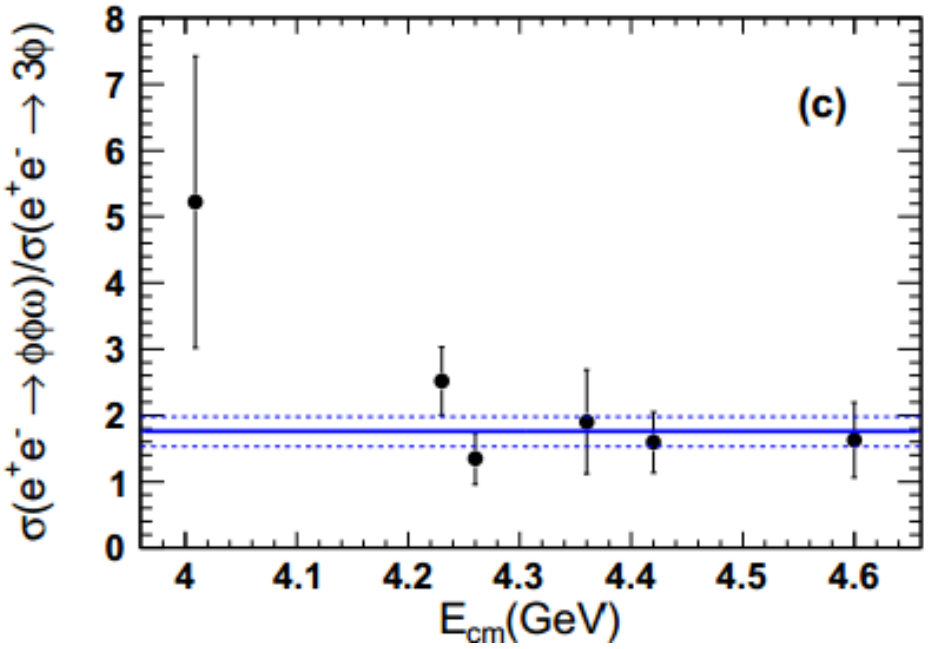


No obvious signal of any vector charmonium-like state.

Born cross sections

Average value of ratio

$$\frac{\sigma(e^+e^- \to \phi\phi\omega)}{\sigma(e^+e^- \to \phi\phi\phi)} = 1.75 \pm 0.22 \pm 0.19$$



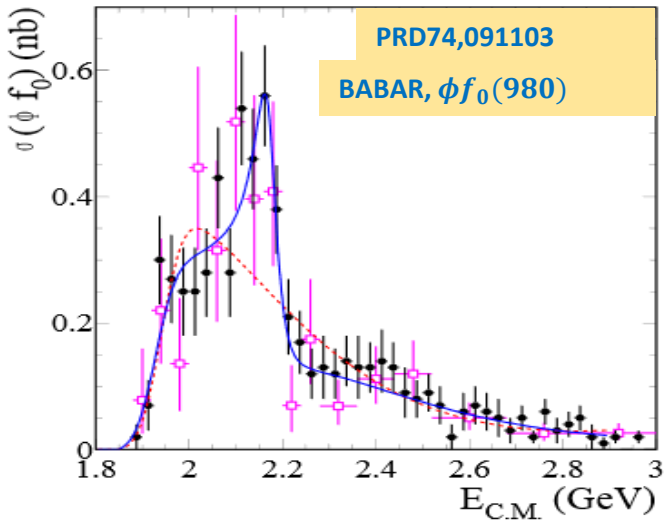
Consist with the expectation.

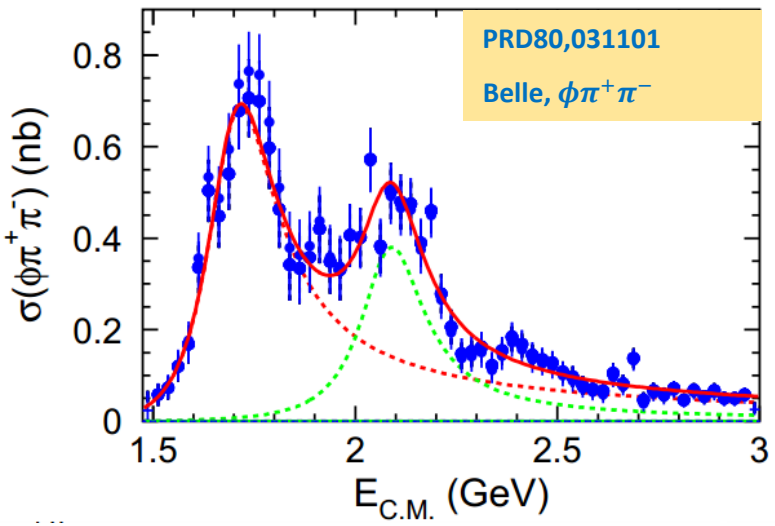
Triple charmonia at Belle II/LHCb?

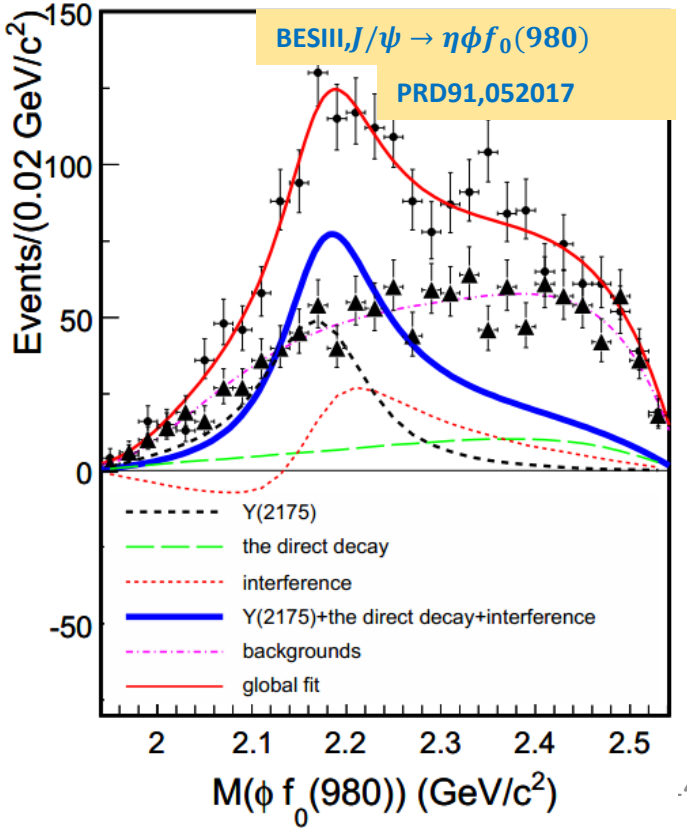
Observation of $e^+e^- \to \eta Y(2175)$ above 3.7 GeV

arXiv:1709.04323

- BABAR using ISR $\phi f_0(980)$ observed $Y(2175)$
- mass: $(2175 \pm 10 \pm 15)$ MeV/c^2, width: $(58 \pm 16 \pm 20)$ MeV
  - Confirmed by Belle, BESII and BESIII
- Similar with $Y(4260)$ and $\Upsilon(10860)$,
- Could be charged $Z_s \to \phi\pi$ in $Y(2175) \to \phi\pi^+\pi^-$,
  close to $K\overline{K^*}$ 和 $K^*\overline{K^*}$ threshold （EPJC72,2008）
- High background
- **BESIII has largest data at 3.7-4.6GeV, can be used to search for $e^+e^- \to \eta Y(2175)$**







Event selections

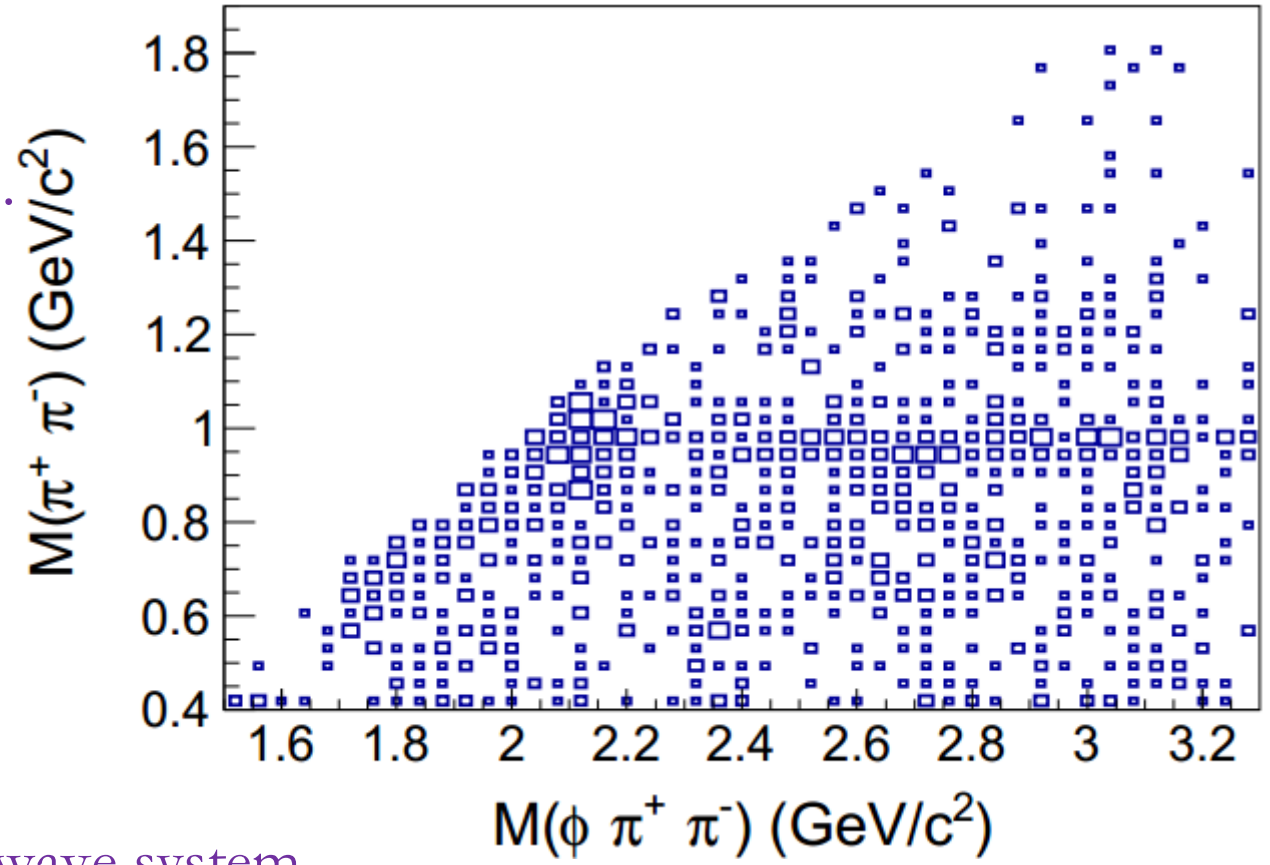
- Four good charged tracks with net charge zero.
- At least two good photons to reconstruct η
- Identify K and π
- 4 constraint kinematic fit, and $\chi^2 < 60$

The $\pi^+\pi^-$ should be dominant by $f_0(980)$.
Clear signal of $Y(2175) \to \phi f_0(980)$
Use the events of $M(\pi^+\pi^-) \in$ [0.868,1.089] GeV

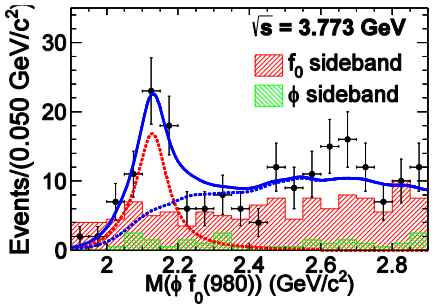
Simultaneous fit for all data above 3.7 GeV with same signal shape:

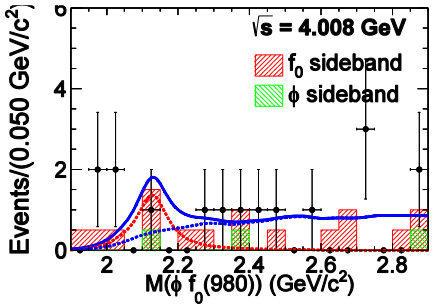
$$\left(\left| \frac{M\Gamma}{M^2 - m^2 - iM\Gamma} \right|^2 \cdot \frac{\Phi(m)}{\Phi(M)} \cdot \epsilon(m) \right) \otimes G(m; 0, \sigma),$$

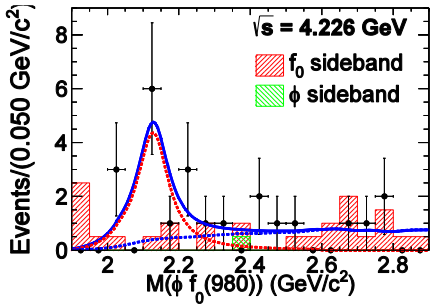
Φ is the phase space factor for two body P-wave system.

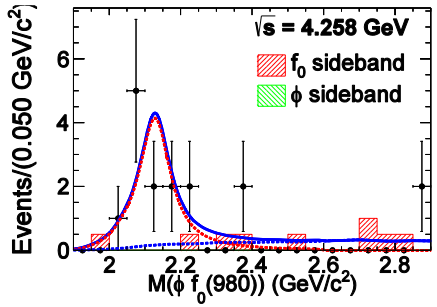


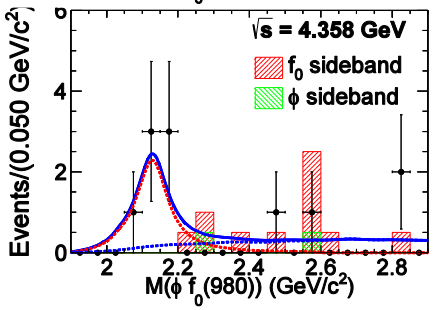
Results of simultaneous fit

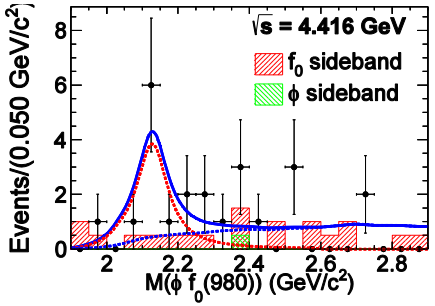


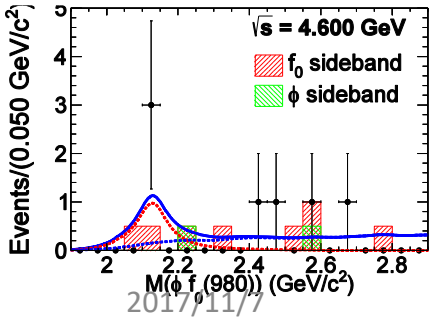


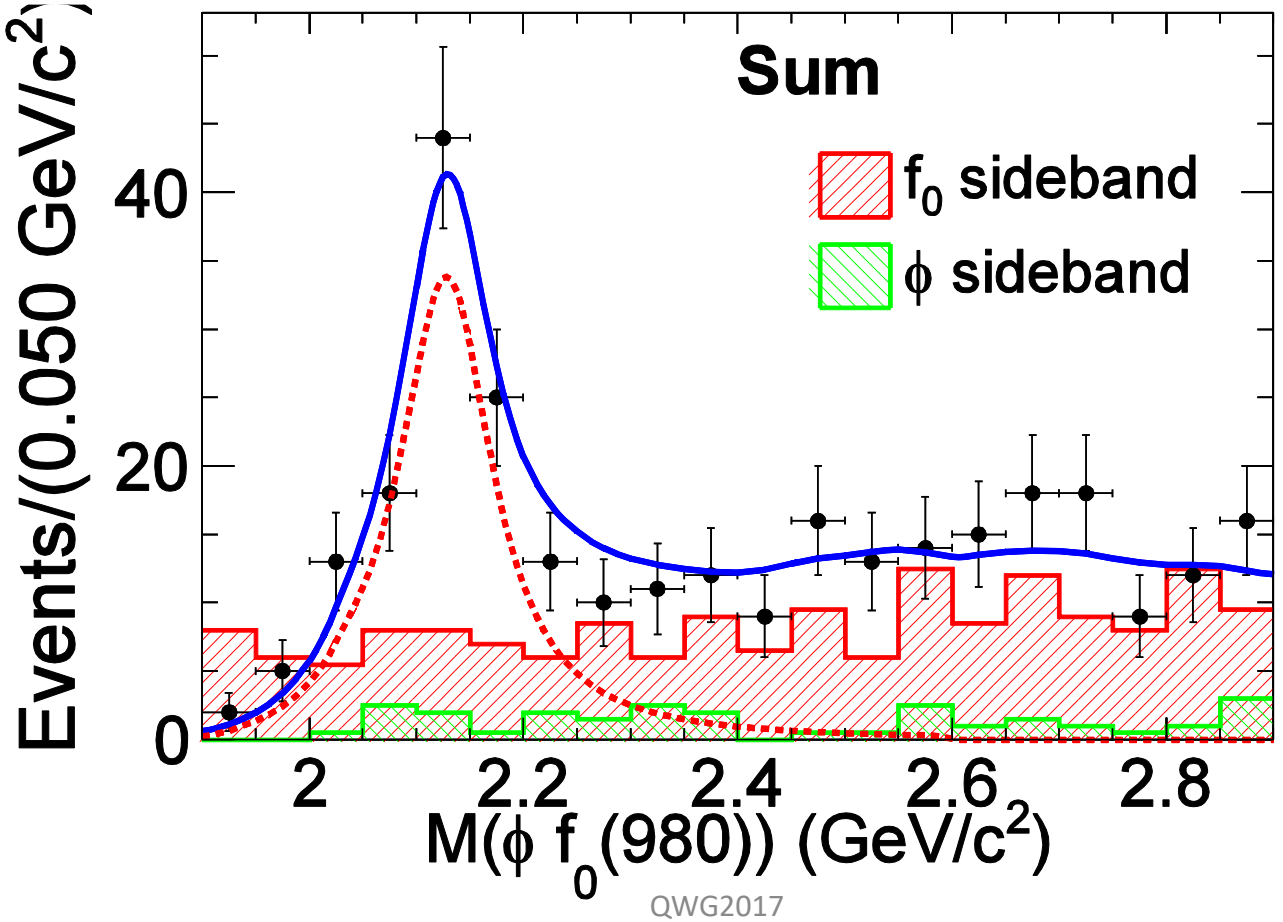












Clear signal.
Lower background level compared to other product processes.

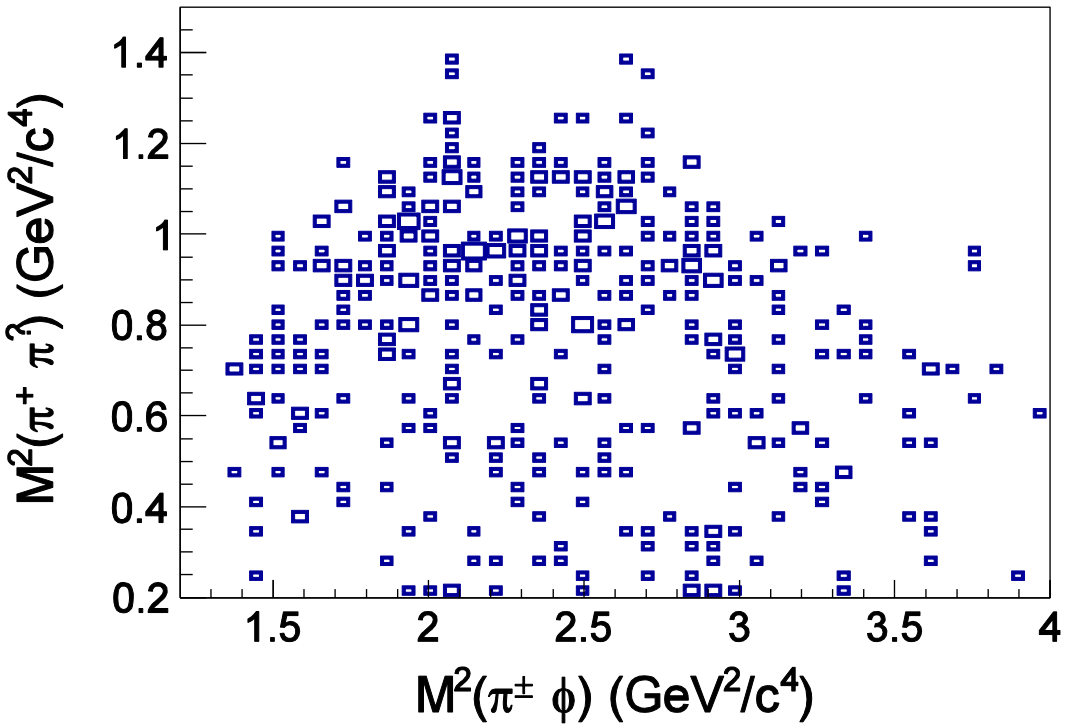
Mass M
$(2135 \pm 8 \pm 9)$ MeV,
Width Γ
$(104 \pm 24 \pm 12)$ MeV

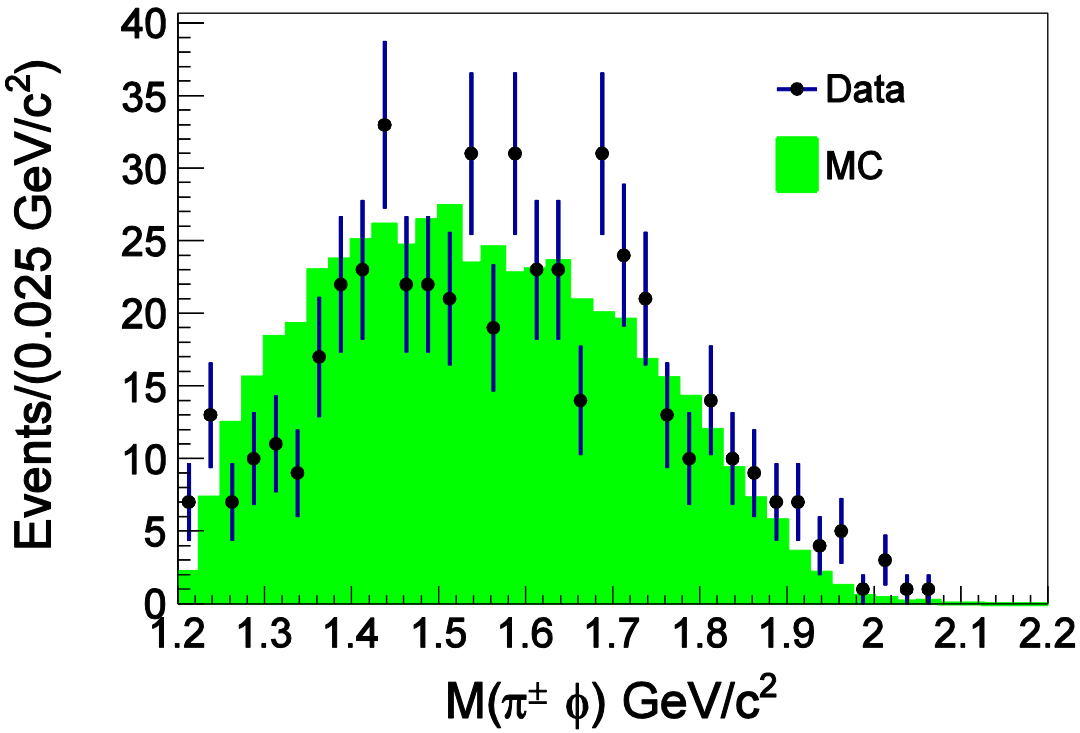
$Y(2175) \to \phi\pi^+\pi^-$ Dalitz plot

Remove the requirement of $f_0(980)$ mass window.

Search for the charged Z_s. No obvious signal.

Background level is lower, with more data, maybe sensitive to search for Z_s





Born cross sections

$\sqrt{s}$ (GeV)	$\mathcal{L}_{\rm int}$ (pb^{-1})	$N^{\rm obs}$	$(1+\delta)\cdot\epsilon$	$1+\delta^{\rm vac}$	$\sigma^{\rm B}$ (pb)	Significance
3.686	666	19.0±9.0	0.0861	-	$1.72 \pm 0.82 \pm 1.00$	1.5σ
3.773	2917	47.4±9.1	0.0865	1.057	$0.93 \pm 0.18 \pm 0.15$	6.2σ
4.008	482	3.8±2.6	0.0976	1.044	$0.40 \pm 0.27 \pm 0.34$	1.0σ
4.226	1092	12.3±4.1	0.1052	1.056	$0.53 \pm 0.17 \pm 0.05$	3.8σ
4.258	826	11.6±3.7	0.1067	1.054	$0.65 \pm 0.21 \pm 0.08$	4.2σ
4.358	540	6.4±2.7	0.1113	1.051	$0.53 \pm 0.22 \pm 0.07$	2.9σ
4.416	1029	10.8±4.1	0.1135	1.053	$0.46 \pm 0.17 \pm 0.21$	3.2σ
4.600	567	2.7±1.9	0.1164	1.055	$0.20 \pm 0.14 \pm 0.02$	1.5σ

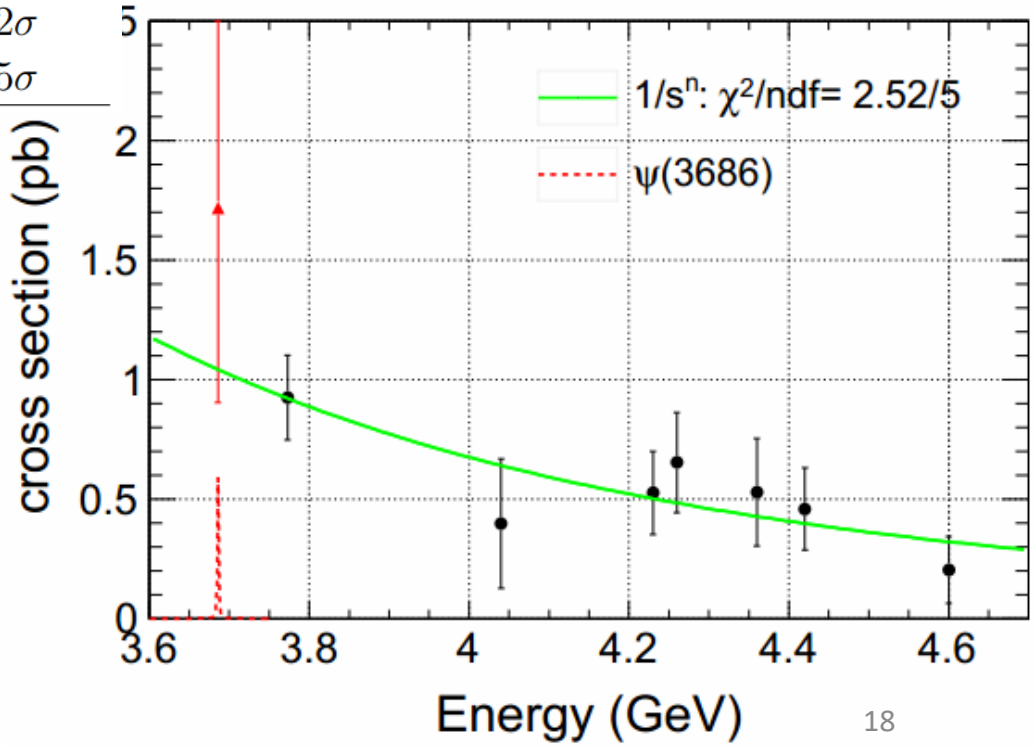
No obvious signal from charmonium(-like), similar with other VP channel:

PRD75,094020

$$\sigma(s) \propto \frac{1}{s^n}.$$

$$n = 2.65 \pm 0.86,$$

Get the Born cross section by iteration



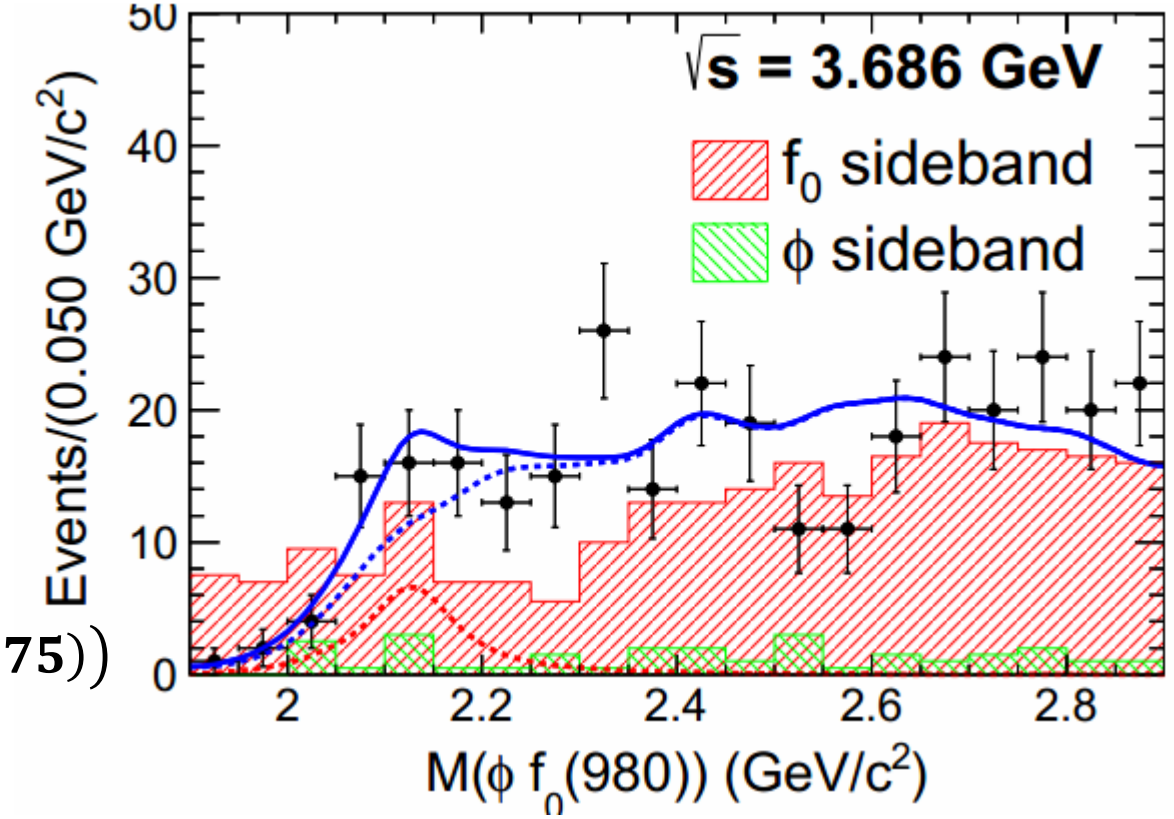
Branching fraction of $\psi(3686) \to \eta Y(2175)$

- Use data above 3.7 GeV to estimate the QED contribution

$$\mathcal{B}\left(\psi(3686) \to \eta Y(2175) \to \eta\phi f_0(980)\right) = (0.81 \pm 0.97 \pm 0.47) \times 10^{-6}$$

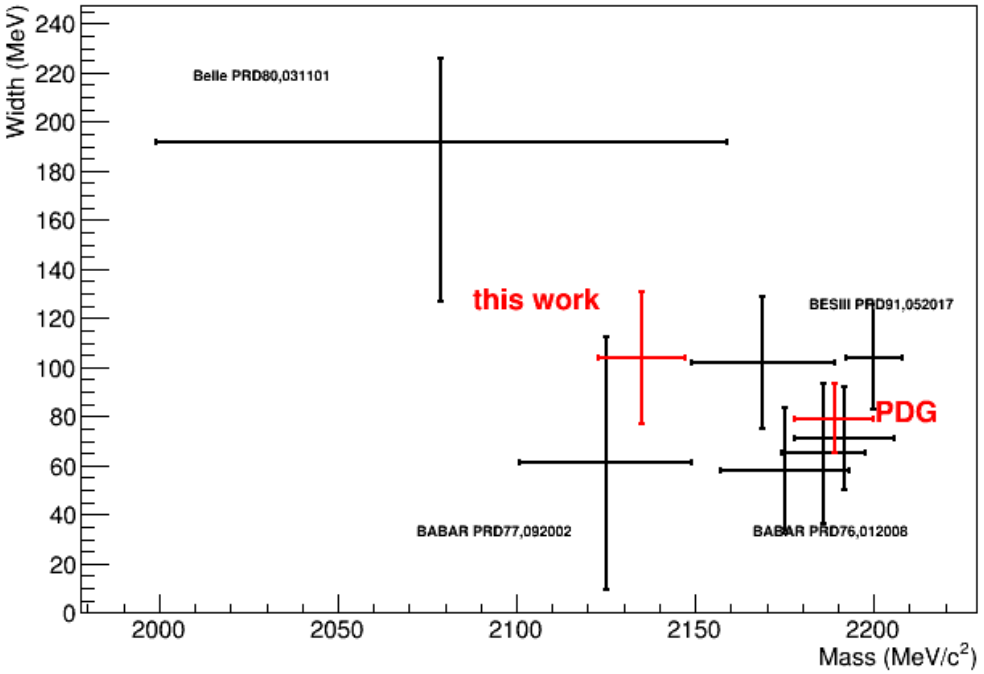
- Combine with the branching fraction of J/ψ and consider the P wave phase space difference:

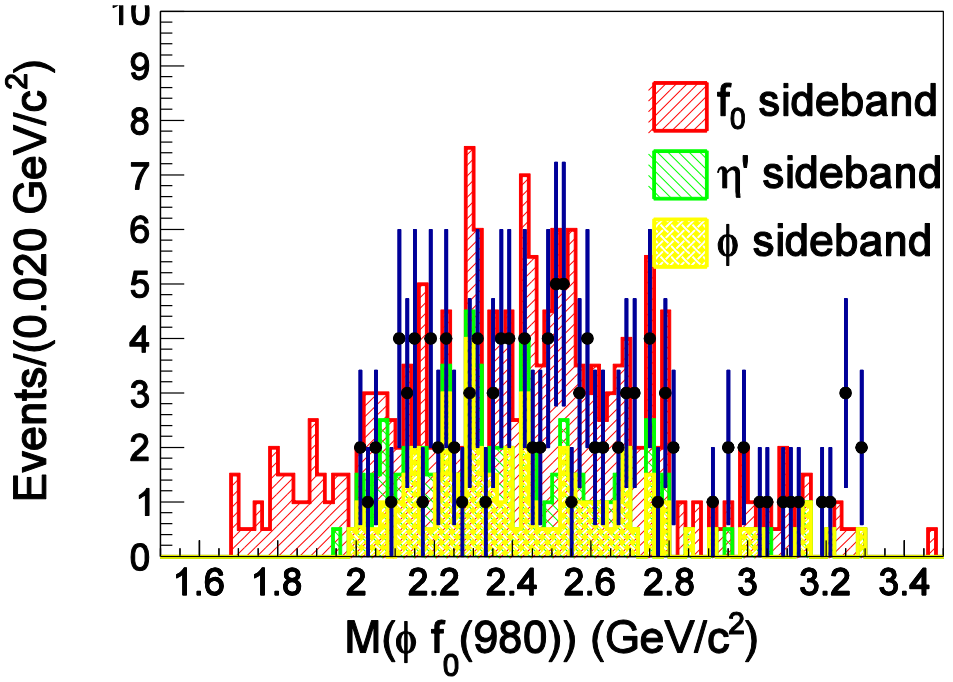
$$\mathcal{B}^*\left(\psi(3686) \to \eta Y(2175)\right)/\mathcal{B}^*\left(J/\psi \to \eta Y(2175)\right) = (0.23 \pm 0.29 \pm 0.13)\%$$



- Huge suppression compared to 12% rule

Background level is higher since the contribution of $\psi(3686)$





Parameters consist with previous results

No clear signal of $\eta' Y(2175)$,

$$R = \frac{N^{\rm obs}_{\eta' Y(2175)}}{N^{\rm obs}_{\eta Y(2175)}} \cdot \frac{\mathcal{B}_{\eta}}{\mathcal{B}_{\eta'}} \cdot \frac{\sum_i \sigma^i_{\eta Y(2175)} \cdot \mathcal{L}^i_{\rm int} \cdot \epsilon^i_{\eta' Y(2175)} \cdot (1+\delta)^i \cdot (1+\delta^{\rm vac})^i}{\sum_j \sigma^j_{\eta Y(2175)} \cdot \mathcal{L}^j_{\rm int} \cdot \epsilon^j_{\eta' Y(2175)} \cdot (1+\delta)^j \cdot (1+\delta^{\rm vac})^j}.$$

Assume the ratio between $\eta' Y(2175)$and $\eta Y(2175)$ are the same,

$$\boldsymbol{R < 0.43, 90\%\ \text{C.L.}}$$

Summary

The cross section of $e^+e^- \to p\bar{p}\pi^0, \phi\phi\phi, \phi\phi\omega$ and $\eta Y(2175)$ are measured with higher energy data at BESIII.

No obvious signal of any charmonium-like state.

Any theoretical predictions on the light hadron decays of $Y(4260)$?

Thanks for your attention.